Spatial Variations of the Wave, Stress and Wind Fields in the Shoaling Zone

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LONG-TERM GOAL

Our long term goals are to improve parameterization of surface fluxes in the coastal zone in the presence of wave growth, shoaling, and internal boundary layer development. These goals include improving the present form of similarity theory used by models to predict surface fluxes and stress over water surfaces and documenting development of internal boundary layers in the coastal zone that are currently not modelled correctly, particularly in cases of flow of warm air over colder water.

OBJECTIVES

Our objectives are to provide quality controlled data sets which include spatial variation of surface fluxes, stress and wave characteristics and provide vertical structure of the wind and thermodynamic variables in the coastal zone. The objectives also include both evaluation of present formulations for surface fluxes at the air-sea interface and evaluation of model simulations of internal boundary layer development.

APPROACH

The first approach has been implementation of an extensive literature survey on existing studies of air-sea interaction in the coastal zone and internal boundary layer development. The second approach is implementation of three field programs, one completed in fall of 1997, one completed in spring of 1999 and one to be completed in fall of 1999. The spring 1999 field program was designed to study the internal boundary layer in offshore flow, particularly in stable conditions. The third approach is data analysis and evaluation of existing boundary layer and surface flux formulations. The fourth approach is model comparisons with other groups.

WORK COMPLETED

The Duck 1999 spring experiment was successfully completed within the adverse weather constraints. In contrast to expectations based on climatology, northerly flow along the coast persisted for much of the experiment. As a result, the LongEZ aircraft flew a significant fraction of the flights over inland water west of Duck and over Lake Mattamuskeet, in order to study offshore flow.

The data has been calibrated and quality controlled. Initial analysis has concentrated on one of the cases of offshore flow southeast of Duck. Ground observations included a sonic at the end of the pier,

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a sonic near the top of the land mast, two 2-dimensional sonics and ten thermistors along the pier and thermocouples on the land tower and at the end of the pier. All of the data has been examined but only a few cases have been studied in detail.

RESULTS

We now report on the results of the case study analysis from the spring99 data. Over the Outer Banks, the sensible heat flux near the surface is positive due to the strongly heated land surface. The heat flux decreases rapidly with height to near zero at one-half the boundary-layer height and becomes strongly negative in the upper-half of the boundary layer. The depth of the entrainment layer where the heat flux is negative is nearly as large as the depth of the surface based convective layer. By 2 km downstream from the coast, the influence of cold water has eliminated the influence of convection over land and a stable surface-based layer develops.

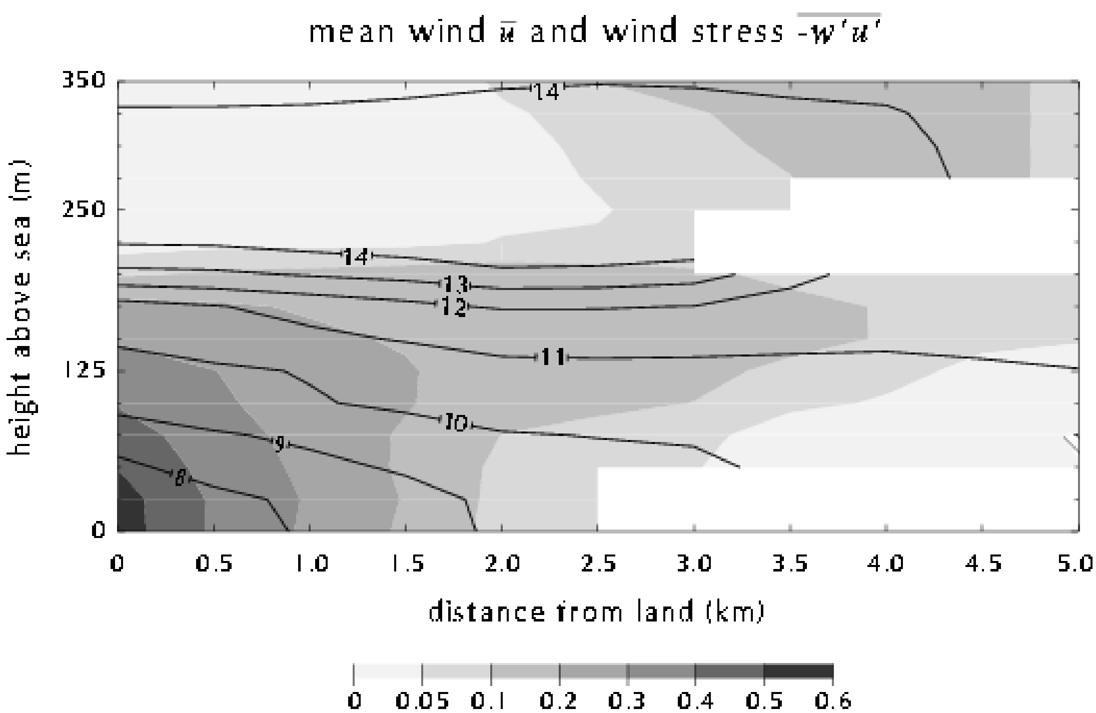

Figure 1. Cross-section of momentum flux (m^2/s^2) and wind speed (m/s) constructed from LongEZ aircraft passes. Blank areas indicate lack of aircraft data.

Beyond a few kilometers downstream, the turbulence becomes partially detached from the surface leading to an elevated wind stress maxima near the top of the boundary layer (Figure 1). The turbulence kinetic energy increases with height from the surface up to the internal boundary layer height for fetches ranging from 2 km to 8 km. In this region, the source of the mixing is aloft rather than at the surface. Beyond approximately 10 km, the elevated turbulence maxima vanishes.

The vertical flux convergence of the wind stress downstream from the coast leads to acceleration of the low-level mean flow in contrast to the usual boundary layer. The initial formation of an elevated turbulence layer beginning a few kilometers downstream from the coast is probably due to the height variation of advective and decay processes.

The turbulence may decay less aloft where the wind speed is larger and therefore the travel time over which it decays is shorter. In addition, the decay rate of the turbulence at low-levels may be faster (smaller decay time scale) due to smaller characteristic mean eddy length scale near the surface. The elevated maxima is intensified and maintained by buoyancy destruction of turbulence near the surface due to the cold water. The air-sea temperature difference ranges from 6 to 8 C, which coupled with the weak low-level wind stress, leads to strongly stable conditions ($z/L = 1$ to 10).

IMPACT/APPLICATION

The boundary layer in offshore flow is characterized by unusual vertical structure. It is not clear at this point if existing models can describe this structure. Our modeling attempts are just underway and indicate that some of the unique observed features can be reproduced but the differences between the observed and modelled flows are substantial. The work during the previous year of the grant indicated that existing surface flux formulations are not correct in offshore flow. Models must be generalized to include a modified flux formulation but must also be able to describe elevated generation of turbulence not directly related to the underlying surface.

RELATED PROJECTS

Analysis of offshore tower eddy correlation data is being carried out under grant N00014-98-0282 from the Office of Naval Research. This data allows analysis of detailed vertical structure in the lowest 40 m whereas the above work concentrates on horizontal structure in the coastal zone.

PUBLICATIONS

Mahrt, L., Dean Vickers, J. Sun, Timothy Crawford, Chris Vogel and Ed Dumas, 1999: Coastal Zone Boundary Layers. 13th Symposium on Boundary Layers and Turbulence. American Meteorological Soc. Dallas. 403-406.

J. Sun, L. Mahrt, Dean Vickers, John Wong, Tim Crawford, Chris Vogel, E. Dumas, P. Mourad and D. Vandemark, 1999: Air-sea interaction in the coastal shoaling zone. 13th Symposium on Boundary Layers and Turbulence. American Meteorological Soc. Dallas. 343-345.